DEVELOPMENT OF A 10 MW, L-BAND MULTIPLE BEAM KLYSTRON FOR TESLA*

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Abstract

A high-efficiency Multiple Beam Klystron (MBK), designated the VKL-8301, is being developed for the DESY Tera Electron volt Superconducting Linear Accelerator (TESLA) in Hamburg, Germany. The design approach is to use six off-axis electron beams interacting with a combination of TM_{010} and hybrid TM_{020} cavities. The six beams are equally spaced on a diameter of approximately 25 centimeters. Because of the large beam-to-beam separation, individual high-area convergence guns can be utilized versus the single multi-emission-site gun used in the conventional clustered-beam approach. The use of six individual cathodes reduces the cathode loading to less than half that for an equivalent clustered-beam cathode. This comes at the expense of a relatively difficult-to-realize focusing system, compounded by the use of confined-flow focusing. State-of-the-art three-dimensional electromagnetics codes [1], [2], [3] have been used to design the novel electron-beam-focusing system and microwave cavity geometry.

1 BACKGROUND

The early development of MBK technology began in the United States with some notable success [4], [5]. It became apparent that the cost to develop reliable devices was significantly higher than their single-beam counterparts; the complexities associated with MBK electron-beam formation, beam transport, and cavity design resulted in these high development costs. As a result, government-sponsored programs focused on alternate solutions, particularly for high-power, broad-band radar applications, where Coupled-Cavity Traveling Wave Tubes (CCTWTs) and Cross Field Amplifiers (CFAs) are currently in use. However, with today's modern computational resources, these devices can be developed at a fraction of what it would have cost thirty years ago.

This was not the case in the former Soviet Union. Considerable development effort was expended perfecting MBK technology, which is in wide use today in many modern industrial and military systems. A recent review of this technology identifies the two categories in which MBKs can be categorized: Fundamental Mode (FM) and Higher-Order Mode (HM) MBKs [6]. The differences between the two are the proximity of neighboring beams and the proximity of neighboring cavity modes.

The FM-MBK consists of as many as 40 electron beams (some authors have proposed more) clustered around the geometric axis, interacting with TM_{010} cavities, and are generally used for applications requiring large instantaneous bandwidth. Techniques have been devised to broadband the frequency response to the extent that FM-MBKs are used in systems normally considered for CCTWTs and CFAs. The primary drawback to this approach is that the clustered electron beams are constrained to fall within a circle of approximately $\lambda_o/4$ for optimum cavity interaction. As a result, the cathode-array diameter is equally constrained, with cathode current density the dependent variable. Typical beam area of convergence is therefore in the range from 3:1 to 4:1 for the individual cathodes.

The HM-MBK consists of as many as 36 electron beams, widely separated one from the other, operating into higher-order-mode cavities. Ring resonators are commonly used. The HM-MBK is selected when relatively narrow bandwidths are acceptable, as with conventional single-beam klystrons, at high average power. The primary drawback to this approach is the relative separation of the desired mode to other modes in the cavity resonator, limiting the usable bandwidth. However, for this geometry, the cathode loading is not constrained by the circuit *per se* and is instead limited by the skill of the beam-optics designer. Beam areas of convergence as high as 30:1 have been used successfully.

An equally important factor is that as a result of beam interception with and without rf, the cavity thermal loading is distributed along a relatively large surface area, increasing the average power handling capability of the HM-MBK versus the FM-MBK. A list of advantages and disadvantages of MBKs relative to single-beam klystrons can be seen below.

Advantages
- Lower operating voltage for a given rf power level
- High efficiency vs. microperveance
- Large instantaneous bandwidths (FM-MBK)
- Compact, lightweight
- Low Noise

Disadvantages
- Difficult to focus the electron beams; high dc and/or rf body current
- Lower average power (FM-MBK only)
- High cathode loading (FM-MBK only)
- Brillouin focusing
- Uniform magnetic focusing field

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2 KLYSTRON DESIGN

The CPI-DESY engineering team agreed to use the HM-MBK approach for the TESLA MBK. The primary reason for doing so is discussed above and worth repeating: low cathode loading combined with distributed thermal loading of the rf circuit. This HM-MBK will use six off-axis electron beams emitted from six individual cathodes. Each cathode has its own heater connection and can be operated independently, which will be useful for diagnostic purposes as described below.

Modulation of the six electron beams occurs in a common, hybrid TM_{020} mode cavity. Coupling to the beams occurs at the second radial electric field maximum. Once modulated, the beams travel through separate drift tubes and are bunched by a series of individual TM_{010} cavities, including a second-harmonic cavity; the gain section consists of six conventional cavity/drift-tube circuits in parallel. Energy extraction occurs in the common output cavity, which again operates in the hybrid TM_{020} mode. Two WR650 waveguides with pillbox windows are used for power transmission. Finally the spent beam is dumped in six isolated collectors. Table I lists the essential design parameters for this device. An outline drawing of the klystron without the magnet can be seen in Figure 1.

Table 1: Klystron Typical Operating Parameters

Parameter	**Value**	**Units**
Peak Output Power	10	MW
Average Output Power	150	kW
Beam Voltage	114	kV
Beam Current	131	A
Efficiency	65-67	%
Frequency	1300	MHz
Pulse Duration	1.5	ms
Saturated Gain	47	dB
Number of Electron Beams	6	
Number of Cavities	6	
Cathode Loading	~2.1	A/cm^2
Solenoid Power	4000	W, max.

2.1 Electron Gun and Beam Optics

The major challenge to the operation of this device will be the proper focusing of the off-axis electron beams. Substantial effort has been committed to the simulation and design of the magnetic circuit. Unique to this HM-MBK is the use of confined-flow focusing. Confined-flow focusing requires substantial magnetic flux to thread the cathode; therefore, it is critically important that the flux tubes be appropriately shaped, with symmetrical convergence about the beam centerlines (i.e. low transverse field).

A goal magnetic field curve was generated from an axisymmetric simulation of the electron-gun beam trajectories. From this, a series of shaped pole pieces were developed to both minimize the transverse field experienced by the beam and to closely approximate the goal curve. Iteration between the XGUN 2.5-D beam-optics code and 3D MAFIA S-400 [3] magnetostatics code was performed until acceptable beam performance in 2.5-D was realized. Confirmation modeling is underway using the 3D programs MAFIA TS3-400 and MICHELLE [1]. Initial results from MICHELLE show good agreement with the XGUN results.

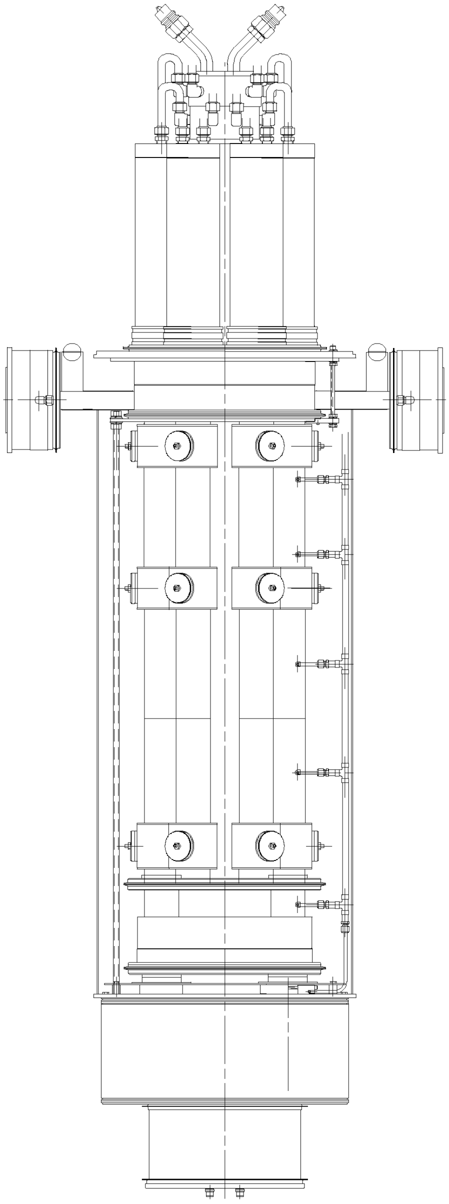

Figure 1: VKL-8301 Klystron Outline

2.2 Microwave Circuit and Windows

The microwave circuit used for the HM-MBK consists of six cavities: a pair of hybrid TM_{020} cavities for the input and output and, between these, four TM_{010} cavities. One of the TM_{010} cavities is tuned to the second-harmonic frequency to enhance efficiency. The four TM_{010} cavities are repeated six times in parallel.

The most challenging aspect of this part of the design was realizing the input and output cavity coupling networks. The cavity coupling network parameters, input loop and output-iris geometry were determined by post-processing the eigenfrequencies [7] obtained from 3D eigenmode solvers MAFIA E-400 and CTLSS[2]. Once the cavity geometry was determined, analysis was performed to investigate the start-oscillation currents of undesirable higher-order modes. The worst-case start oscillation current was more than double the beam current indicating that the hybrid TM_{020} cavities are unconditionally stable.

2.3 Collector

The first prototype has been designed with six isolated collectors. This for monitoring of the beam interception on each beam independently; the dc transmission of individual beams can be checked before operating all six simultaneously. This does increase the cost of the prototype; however, the information received from the prototype will allow us to fine-tune follow-on units.

3 SUMMARY

CPI is developing a state-of-the-art MBK for use on the TESLA accelerator. A review of the relative strengths and weaknesses of the two MBK categories show the HM-MBK as the clear choice for this application. A novel approach has been taken to realize the electron-beam-focusing system and hybrid cavity design. The use of state-of-the-art 3D computer modeling makes this effort technically and fiscally viable. As currently scheduled, the design phase will be completed by mid-2002, and the prototype klystron will be in test by December of 2002.

4 ACKNOWLEDGEMENTS

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